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Assessment of Soil Organic Carbon Stock Under Tea Agroforestry System in Barak Valley, North East India

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ABSTRACT

Quantification of soil organic carbon (SOC) stock can be considered as effective evaluation of soil quality and carbon dynamics in tropical agroforestry systems (AFS). We investigated distribution of soil organic carbon (SOC) stock in different soil layers up to 1 m depth under an age sequence of tea AFS in Barak Valley, North East India. SOC stock in the system ranged from 65.14 to 141.49 Mg C ha^{-1} with a mean of 101.39 Mg C ha^{-1}. About 46% of estimated SOC was confined to 0-30 cm layer whereas 65% of SOC occurred in the 0-50 cm soil layer. The next soil layer (50-100 cm) accounted for about 36% of estimated SOC. SOC decreased with increasing depth in all the plantations and was negatively related with bulk density (BD). Healthy management of tea plantations to higher age can be considered a beneficial approach to store sizable amount of SOC providing environmental services coupled with economic gain.

Key Words: Carbon Stock; Soil Texture; Walkley and Black Method

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has recognized soil organic carbon (SOC) pool as one of the major carbon (C) pools for the Land Use, Land Use Change and Forestry (LULUCF) sector (Penman et al. 2003). SOC is the largest terrestrial C pool with global estimated 684-724 Pg of C in upper 30 cm and 1462-1548 Pg of C in the upper 100 cm (Batjes 1996). SOC is considered to be of primal importance in maintaining soil quality and closely associated with a wide range of physical, chemical, and biological properties of soil, and therefore plays a key role in soil processes and functioning (Smith et al. 2000). Its content is recognized as a key component of soil fertility, and hence, maintaining a satisfactory SOC content is a major determinant of the productivity and sustain-ability of terrestrial ecosystems (Reeves 1997). Sequestration of atmospheric carbon dioxide (CO_2) in the soil, as stable soil organic matter, provides a long lasting solution to decrease the CO_2 in the atmosphere. To evaluate C sequestration processes in the soils, it is necessary not only to examine the total C stock but also to determine the durability of the SOC. Plant growth and developments are mostly governed by the existing soil conditions. Agroforestry systems (AFS) spread over one billion ha in diverse ecoregions affecting 558 million people around the world (Zomer et al. 2009). These woody perennial-based land use systems have relatively high capacities for capturing and storing atmospheric CO_2 in vegetation, soils and biomass products (Nair 2011).

Tea (*Camellia sinensis* (L.) O. Kuntze) agroforestry system has the ability to couple economic gains with social services and environmental benefits. It has widespread implications for the earnings and food security of farm communities, particularly smallholders in the countries of Asia, Africa and the Near East. Tea cultivation is confined only to specific regions with hot and humid climatic conditions due to its specific requirements of climate and soil. Tea plantations in India occupy a large acreage of agricultural land measuring over 579, 350 ha (Tea Board of India, 2007). In Barak Valley tea is grown under canopy of shade trees (dominated by *Albizia odoratissima*, *A. lebbeck* and *Derris robusta*) (Kalita et al. 2014) and occupies 5.75% of total geographical area (Das and Das 2013). Understanding soil fertility dynamics in this extensively managed system could provide decision support for the rational use of fertilizer to improve the yield and quality of tea along with environmental services through climate change mitigation. Tropical areas are characterized by high risk of soil and environmental degradation because of rapid decomposition of soil organic matter under favorable environmental conditions. Thus, possible nutrient depletion and loss of soil organic matter are of great concern. As a component of the terrestrial C cycle, soil can be either source or sink of atmospheric CO_2 (Lal 2004). Precise measure of SOC is needed to generate benchmark information for the present and to determine the future changes in systems like tea agroforestry. No systematic study has been made on this aspect in India. Hence, this study aimed to evaluate SOC stocks in different soil layers to a depth of 1 m under tea AFS in North East India.

Study Area

The study was conducted in tea AFS of Cachar District (latitude 24° 22' and 25° 8' N; longitude 92° 24' and 93°15' E) of Barak Valley, Northeast India. The region covers an area of 6922 km^2 with highly undulating topography characterized by hills, hillocks, wide plains and low lying waterlogged areas. Most of the hills have a north south spread interspersed by strips of plain areas. The study site altitude ranges from 14 m to 56 m above sea level. The study site experiences sub-tropical, warm and humid climate with average rainfall of 2390 mm, most of which is received during the southwest monsoon season (May-September). The mean maximum and mean minimum temperatures range from 25.4 °C and 11.2 °C respectively, in January to 33.5 °C and 25.3 °C in August.

MATERIALS AND METHODS

Soil Sampling

Soil samples were collected from twenty plantations varying in their age. Soil samples were collected in triplicate at depths of 0-30 cm, 30-50 cm and 50-100 cm. A composite sample was prepared for each depth, air-dried, ground and sieved through a 2-mm sieve and stored in plastic container. Oven dried samples sieved with 100 no. mesh were utilized for SOC estimation. Triplicate samples of each soil depth for each site were analyzed for physicochemical characteristics.

Soil Parameters

Soil texture was determined by Bouyoucos (1962) soil hydrometer method (type ASTM no.152 H) and bulk density (BD) by Corer technique (Brady and Weil 2008). Water holding capacity (WHC) was determined using Keen’s box method (Keen and Raczkowski 1921). Soil pH was measured in a 1:2.5 soil:water suspension. Organic carbon content of the soil was estimated by Walkley and Black’s rapid titration method (Walkley and Black 1934). Soil organic carbon density (Mg Cha^{-1}) was computed by multiplying the SOC concentration in a sample (gC kg^{-1}) with the corresponding depth and bulk density (Mg m^{-3}).

Statistical Analyses

All data were entered and arranged for analysis using Microsoft Excel 2010 version. Kolmogorov-Smirnov and Shapiro-Wilk Tests were made to check normality of the data. Data were subjected to statistical analysis of variance (ANOVA) for comparing the differences between SOC density in different depths and plantation of different age following LSD to test differences among means in different parameter. Non parametric statistics was adopted for the data sets following non-normal distribution. Regression and analysis were performed using SPSS 20 for windows.

RESULTS

Physicochemical Properties of Soil

Soil texture analysis revealeddominance of loam soil on top and sandy clay loam on middle and bottom layers (30% of occurrence).Distribution of sand, silt and clay across different age group varied significantly (Kruskal– Wallis test, $P < 0.05$). Sand emerged as the dominant constituent of soil followed by Silt and Clay having proportionate contribution of 39%, 33% and 28% in the respective layers across the plantations.

Table 1. Soil physicochemical properties in different age groups under tea agroforestry system in Barak Valley, Northeast India

Age (Yr)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Silt+Clay (%)	BD (g cm^{-3})	WHC (%)	SOC (%)	pH
5-10	0-30	49.73 ± 5.89	27.83 ± 3.74	22.44 ± 2.51	50.27 ± 5.89	1.21 ± 0.13	48.88 ± 2.91	1.36 ± 0.12	4.76 ± 0.07
	30-50	47.91 ± 5.23	24.48 ± 2.67	27.61 ± 3.53	52.09 ± 5.23	1.22 ± 0.14	47.78 ± 1.64	0.76 ± 0.09	4.86 ± 0.12
	50-100	47 ± 7.50	22.15 ± 1.94	30.85 ± 6.12	53 ± 7.50	1.31 ± 0.13	47.79 ± 1.99	0.56 ± 0.09	4.86 ± 0.13
10-15	0-30	48.66 ± 8.09	30.93 ± 6.42	20.41 ± 2.89	51.34 ± 8.09	1.30 ± 0.07	45.03 ± 2.18	1.19 ± 0.11	4.88 ± 0.19
	30-50	41.28 ± 9.45	31.04 ± 7.70	27.68 ± 2.82	58.72 ± 9.45	1.44 ± 0.09	50.10 ± 2.72	0.67 ± 0.08	4.90 ± 0.13
	50-100	45.74 ± 7.56	27.12 ± 5.96	27.15 ± 2.93	54.26 ± 7.56	1.51 ± 0.06	47.49 ± 2.67	0.43 ± 0.07	4.95 ± 0.14
20 - 25	0-30	37.11 ± 11.87	37.91 ± 6.71	24.98 ± 5.5	62.89 ± 11.87	1.18 ± 0.07	52.63 ± 3.09	1.18 ± 0.18	4.94 ± 0.23
	30-50	35.78 ± 12.73	34.9 ± 6.01	29.32 ± 7.01	64.22 ± 12.73	1.24 ± 0.07	53.48 ± 3.29	0.77 ± 0.12	5.03 ± 0.31
	50-100	35.81 ± 12.58	32.29 ± 6.53	31.9 ± 6.44	64.19 ± 12.58	1.34 ± 0.08	53.25 ± 3.74	0.71 ± 0.15	5.03 ± 0.35
25 - 30	0-30	25.74 ± 8.71	44.49 ± 5.78	29.77 ± 5.96	74.26 ± 8.71	1.31 ± 0.05	55.04 ± 4.59	1.28 ± 0.20	4.63 ± 0.13
	30-50	24.36 ± 8.38	45.38 ± 6.14	30.26 ± 3.71	75.64 ± 8.38	1.39 ± 0.04	52.95 ± 2.81	0.66 ± 0.06	4.67 ± 0.13
	50-100	25.34 ± 6.46	47.49 ± 7.19	27.18 ± 3.43	74.66 ± 6.46	1.49 ± 0.03	53.29 ± 1.74	0.43 ± 0.08	4.88 ± 0.15

Values ± SE; BD = bulk density; WHC = water holding capacity; SOC = soil organic carbon

Sand proportion declined along with depth whereas Clay proportion in soil showed gradual increase along with depth across plantations (Table 1). BD values ranged from 0.84–1.73 Mg m $^{-3}$.Median values for BD in the top, middle and bottom soil layers estimated were 1.29, 1.34 and 1.44 respectively (Figure 1). BD value increased significantly across soil depths (Kruskal–Wallis test, P <0.05). WHC ranged from 38.2% to 69.2%. Soil pH values across all the plantation sites and concerned soil horizons ranged 4.25–6.39, i.e, the soils were strongly acidic. The pH values increased with increasing soil depth across different age groups but did not exhibit notable difference through different plantation age and soil depth. pH values in different plantation age groups varied significantly (Kruskal-Wallis test, P <0.05). Depth-wise soil physicochemical properties of different plantation age groups are presented in Table 1.

SOC Proportion and Stock Distribution

SOC% in the present study ranged between 0.21% - 1.75% across different depth and plantation age groups. SOC% exhibited range of 0.67–1.75%, on top soil, 0.41–1.17% in middle layer and 0.21–1.21% in the bottom layer across different plantations carrying median values 1.26%, 0.74% and 0.46% in respective depths (Figure 2). Multiple comparison statistics showed that SOC% in the top soil layer is significantly higher than in the middle and bottom soil layers (Figure 2). SOC% showed substantial difference across soil depth in plantations of all age groups (Kruskal-Wallis test, P <0.05) but mean SOC% did not vary significantly among age groups (Figure 3).

Mean SOC stock in this study was estimated at 101.39 Mg C ha^{-1} up to 1 m depth. The values ranged from 65.14 Mg C ha^{-1} to 141.49 Mg C ha^{-1} across different soil depths in the plantations.

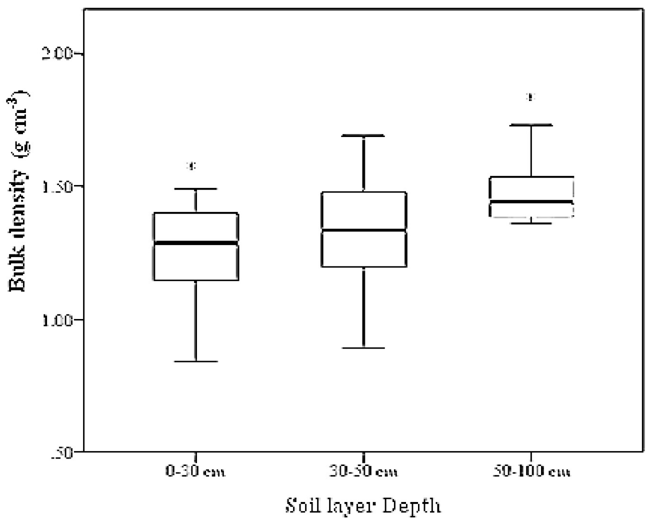

Figure 1. Box plots of Bulk density (gc m^{-3}) values for different soil layer depth; the horizontal line within each box represents the median values for the respective depth.* mark indicates a significant difference of values (p< 0.05).

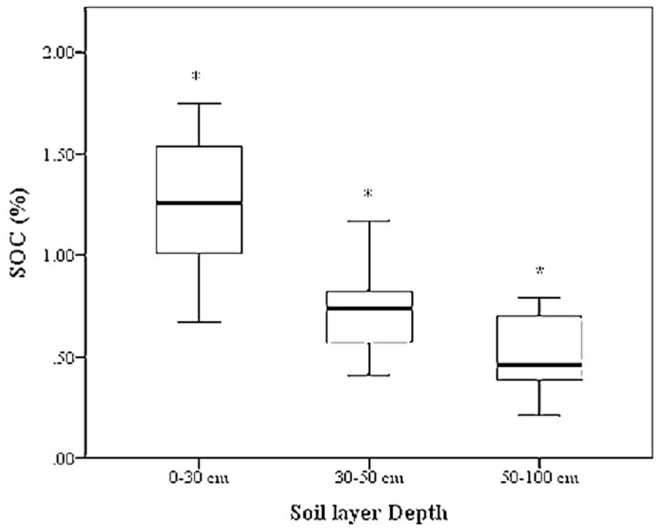

Figure 2. Box plots of SOC (%) values for different soil layer depth; the horizontal line within each box represents the median values for the respective depth. * indicates a significant difference of values ($p < 0.05$)

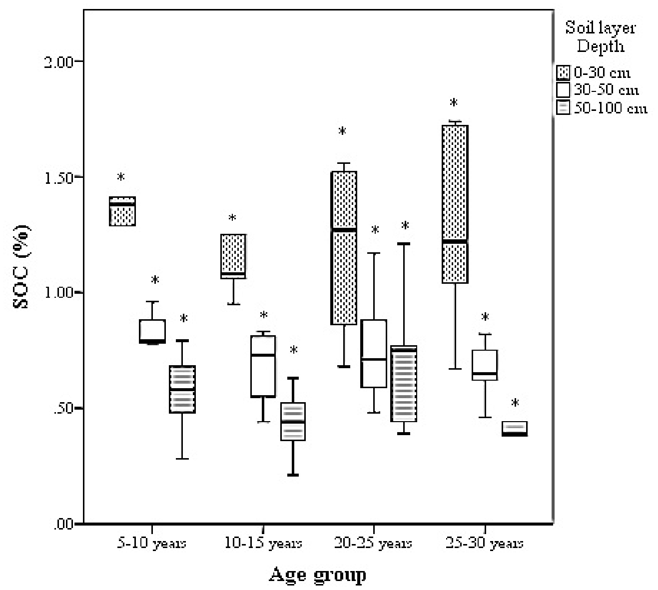

Figure 3.Vertical distribution patterns of SOC (%) across different age group of tea plantations. Different letters marked between two depths indicate a significant difference. * indicates significant difference between two depths ($p < 0.05$) in the respective age groups according to multiple comparison tests .

Among different age groups maximum SOC stock (105.68 Mg C ha^{-1}) was estimated in 20–25 years and 10–15 years age group exhibited minimum (97.59 Mg C ha^{-1}) stock (Table 2). SOC stock showed decreasing trend along with age up to 10–15 years age group and then exhibited higher values in older age groups (Figure 4). SOC stock across plantations and among concerned age groups varied significantly (t - test, $P < 0.01$). In the dataset 46.4% (41% - 50%) of estimated SOC up to 1 m depth was confined to upper 30 cm and this proportion grew to 65% up to 50 cm depth. Bottom soil (50-100 cm) SOC stock was estimated 36.4%. Proportionate distribution of SOC stock on top soil showed decreasing trend from younger to 20–25 years age group and presented higher value in the following age group. Middle layer displayed almost similar proportion of SOC density across all age groups. In bottom soil horizon proportion of SOC stock from 5–10 to 10–15 years age group gradually decreased but higher proportion observed in older plantations (Table 2). The SOC stock decreased with increasing depth in all the age groups and the difference was statistically significant (ANOVA, $P < 0.01$). Descriptive statistics for SOC stock in tea agro-forestry system is summarized in Table 2.

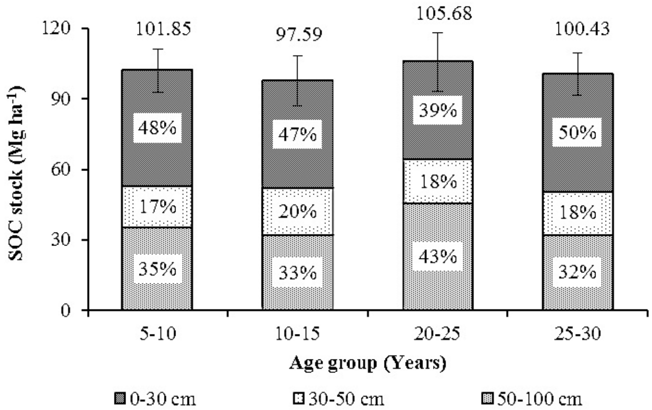

Figure 4. SOC stock (for 1 m depth) and depth wise proportionate distribution in five different plantation age groups.

Relationship of Soil Parameters

Clay proportion showed significant correlation with soil organic carbon (SOC%) in top and bottom soils ($r = 0.61$ and $r = 0.49$; $p < 0.05$).Sand proportion was gradually replaced by clay to some extent in the lower soil depths. WHC displayed positive correlation with clay ($r = 0.79$) and silt ($r = 0.37$) and negative correlation with sand ($r = 0.77$) proportion. BD displayed significant negative correlation with SOC% ($r = -0.45$, $P < 0.01$,) across all the age groups in the dataset. Depth wise differences in BD and SOC% relationship for different age groups of plantations is plotted in Figure 5.

Table 2. Descriptive statistics for SOC stock in different age groups under tea agroforestry system in Barak Valley, Northeast India

Age group (Yr)	Depth (cm)	SOC Stock (Mg ha^{-1})	SOC (Mg ha^{-1}) up to 100 cm			
			Mean ± SE	Minimum	Maximum	CV (%)
5-10	0-30	48.80 ± 4.41	32.58	61.42	20.21	101.85 ± 9.35
	30-50	17.74 ± 1.78	12.85	23.33	22.45	
	50-100	35.30 ± 4.26	21.84	48.87	26.96	
10-15	0-30	45.50 ± 5.49	31.15	67.93	26.99	97.59 ± 10.71
	30-50	19.77 ± 1.89	14.73	25.20	21.36	
	50-100	32.31 ± 4.89	15.12	48.36	33.81	
20 - 25	0-30	41.41 ± 5.43	23.27	59.26	29.32	105.68 ± 12.43
	30-50	18.72 ± 2.10	11.10	24.13	25.03	
	50-100	45.55 ± 5.81	29.63	62.02	28.54	
25 - 30	0-30	49.72 ± 6.96	26.11	67.06	31.29	100.43 ± 9.13
	30-50	18.39 ± 1.86	12.61	25.14	22.60	
	50-100	32.32 ± 5.52	18.32	55.26	38.17	

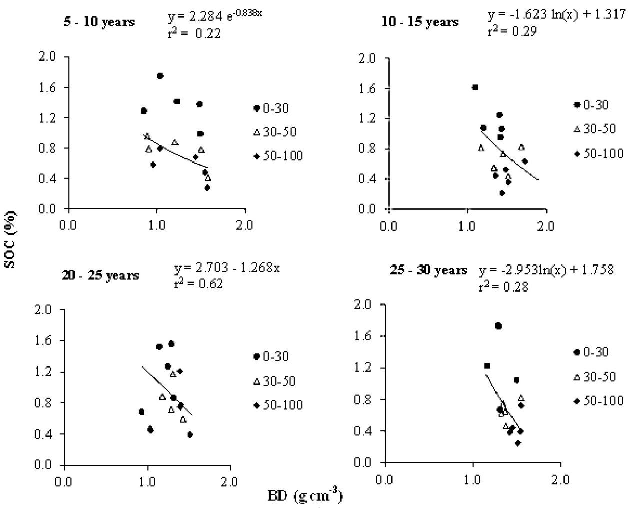

Figure 5. Relation between bulk density (BD) and soil organic carbon concentration (SOC %) at different age groups of plantations. Data for three soil depths are plotted and the regression equations are noted together with r^2 values.

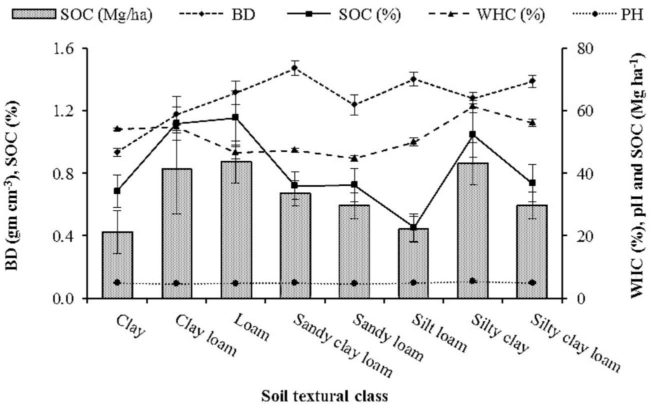

Figure 6. Variation in different soil parameters with soil texture in tea agroforestry system. WHC: water holding capacity; SOC: soil organic carbon; BD: bulk density

Among the textural classes, loam soil holds maximum SOC (1.44%) followed by silty clay (1.40%) and sandy clay loam (1.30%) in top soil. In the middle layer, clay loam (0.99%) lets in maximum SOC followed by silty clay (0.80%) and clay (0.79%). In the bottom layer, clay loam (1.21%) soil has maximum SOC followed by silty clay (0.76%) and clay (0.58%). Distribution of WHC and BD differs significantly across different soil textural classes (Kruskal-Wallis test, $P < 0.05$). Loam, clay loam and silty clay soils exhibited higher potential than that of other textural classes to stock maximum concentration of SOC. Data on various soil parameters across different textural classes are presented in Figure 6.

DISCUSSION

Relationship of Soil Properties

Soil texture, which is fairly a constant property, influences its physico-chemical properties of soil. The BD, WHC, pH and SOC% were observed to be influenced by soil textural classes in the present study. Texture and organic carbon relationships have been well recognized (Zinn et al. 2005) and exhibited resemblance with this data set. Clay and silt proportions do not show significant relationship with SOC% in top soil but clay content influences SOC% in lower layers. Vertical migration of clay and finer particles to lower depths due to siltation may induce this fact. Texture class and horizon displayed impact on SOC % in this study which resembles with the findings of De Vos et al. (2007). Increased proportion of clay in the sub soil layers promoted soil organic matter and may serve as a promoter of nutrients enhancing water absorbance and soil microbial activity. Top soil displayed greater affinity of clay proportion towards SOC more clearly than sub soil horizons. BD exhibited reverse significant correlation with SOC concentration with impact of soil depth. BD values with increasing SOC concentration exhibited more intensity in comparatively lower concentration of SOC in middle and bottom soil layer in this study resembles with the findings of Schrumpf et al. (2011). Depth wise BD and SOC relationship is more consistent in middle and bottom soil horizon and BD is an effective soil parameter determining considerable amount of SOC density despite comparatively lower concentration of SOC in sub soil horizons compared to top soil (Fig. 5). In higher age groups WHC presented higher value compared to lower age group of plantations. WHC displayed wide range and did not show marked difference within soil horizons but closely associated with texture and influenced SOC. Soil pH values observed in the present study (4.25–6.39) measured comparatively higher than pH estimated (3.52–4.40) in tea soils (0–20 cm) under different management systems in eastern China (Han et al. 2013). The relationship of BD and SOC with soil depth, and BD and clay proportion with SOC across soil depths in tea agroforestry systems was similar to that in the agricultural soils of Indo-Gangetic plains (Singh et al. 2011).

SOC Proportion and Stock Distribution

Land under tea agroforestry system in Barak Valley contains substantial amount of SOC density. Estimated SOC density (0–100 cm depth) in the present study (101.39 Mg C ha^{-1}) records higher values than SOC stock in AFS consisting *Alnus nepalensis* (60 MgC ha^{-1} up to 0-75 cm depth) in subtropical hill agro-ecosystems of north-east India (Ramesh et al. 2015), shaded *Theobroma cacao* farms (90 Mg C ha^{-1}) in Cameroon (Norgrove and Hauser 2013) and comparable to average SOC density (0–60 cm depth) figured in tea plantations in China (137.5 Mg C ha^{-1}) (Li et al. 2011). The estimates (77.61–135.61 for 1 m soil depth) for soils under tea agroforestry systems are substantially higher than agricultural soil C stocks of Indo-Gangetic plains (Singh et al. 2011).Mean SOC concentration values in top (0–30 cm) layer of soil in the present study (Table 1) were comparatively higher than the TOC estimated from surface soil (0–15 cm) under tea plantations in Dibrugarh and Tinsukia Districts, Assam, India (Karak et al. 2015). However, TOC figure offered higher values in soils (0–20 cm) under different tea growing regions of West Bengal, India (Ray and Mukhopadhyay 2012). SOC stock up to 30 cm depth ranged between 18.77 - 67.07 Mg C ha^{-1}with mean value of 46.74 ± 2.85 in this study. These values are comparable to the estimates of SOC under shaded cacao agroforestry systems in Bahia, Brazil (Gama-Rodrigues et al. 2010).This estimation shows relatively lower value than alder (*Alnus nepalensis*) - cardamon (*Amomum subulatum*) agroforestry stands of Sikkim Himalaya which exhibited value of 85 ± 6–116 ± 15 Mg C ha^{-1} in a 40 year chronosequence (Sharma et al. 2009). SOC stock data pointed a decreasing trend with increase in age of plantation and subsequently an increase after 10-15 years age. Management practices, intensive tillage and prominent intake of organic matter by the vegetative components (tea bushes and shade trees) in this age group may have caused the decline of SOC stock. Fertilization, subsequent pruning and increased litter accumulation on floor may contribute to increased microbial activity in soil resulting higher SOC in older plantations. Maintenance of tea plantations to higher age can be considered as beneficial approach to store sizable amount of SOC providing environmental services coupling economic gain. Hence there is deficit of reporting SOC stock in agroforestry systems in northeast India it is difficult to compare these findings with similar land use systems under similar environmental conditions.

CONCLUSION

This study provides an account of soil characteristics under tea agroforestry system. Assessment of soil organic carbon stocks in different soil depths under chronosequence of different ages in tea agroforestry systems revealed the potential of the system towards carbon stock in soil compartment. Healthy management practices like conservation tillage, proper shade, surface mulching, compost application, maintenance of floor litter mass etc. may be considered as beneficial attributes for maintaining soil C reserve under tea agroforestry system.

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